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Thomas Hempell

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Computers and Productivity

How Firms Make a General Purpose Technology Work

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With 8 Figures
and 40 Tables

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To my parents

Preface

When it comes to personal experience with computers, everybody can tell stories of breakdowns, inaccessible software, viruses, and other little disasters. During the work on my dissertation, I was no exception in this respect; but I found out how lucky I was to work in an environment of engaged and cooperative colleagues who helped to keep these disasters very small. It thus should come at no surprise that one result of this book is that the benefits from computer use crucially depend on the people involved in joint work.

Most of the studies of this book originate from the research project "ICT as a General Purpose Technology" commissioned by the Landesstiftung Baden-Württemberg foundation, a project that was initiated to quantify the productivity effects resulting from computer use for firms in Germany. I am indebted to my supervisor Werner Smolny for his continuous advice and for supporting my academic work. Moreover, I am grateful to Bernd Fitzenberger and Rüdiger Kiesel for their critical and constructive comments. I also thank Manuel Arellano whose excellent lectures on panel econometrics at Pompeu Fabra University in Barcelona helped me a lot in acquiring the methodological tools necessary for my empirical work.

I would also like to thank my colleagues at the Centre for European Economic Research (ZEW) in Mannheim, in particular Irene Bertschek, who greatly encouraged and supported my research work, as well as François Laisney who patiently assisted me in various econometric questions. In addition, I owe much to the distinct commentaries resulting in fruitful discussions with Dirk Czarnitzki, Günther Ebling, Julia Häring, Ulrich Kaiser, Georg Licht, Martin Schüler, Alexandra Spitz, Elke Wolf and Thomas Zwick. I would also like to thank Meral Sahin for her excellent research assistance.

Without doubt, my wife Bärbel was by far the most important source of support during my work on the dissertation. I am very grateful to her for continuously encouraging me in my work and for bearing with me in times of mental absence. I am particularly happy that the finishing of the dissertation coincided with the beginning of a most wonderful and inspiring joint experience with her: the birth of our son Joschu.

Mannheim, July 2005 *Thomas Hempell*

Contents

1 Introduction

There is no reason for any individual to have a computer in his home.

Ken Olsen, founder of Digital Equipment Corporation (DEC), 1977

Conventional economics is dead. Deal with it!

Mark McElroy, IBM Global Knowledge Management Practice, in *Wall Street Journal*, 2000.

There are two things in particular that it [the computer industry] failed to foresee: one was the coming of the Internet (...); the other was the fact that the century would end.

Douglas Adams, *The Salmon of Doubt*, 2001

During the late 1990s, discussions about computers and the Internet frequently culminated in the proclamation of a *New Economy*, an economic paradise characterised by sustained productivity growth, soaring stock markets and a lot of fun at the job. Written four years after the end of the hype in 2000, this monograph is about what might be left about these dreams: the potentials and the difficulties that firms face in using information and communication technologies (ICTs) productively.

Entering 'new economy' as key words in the Internet search engine *Google* in 2004 yields an 'Encyclopedia of the New Economy' as the top result.[1] This web site provided by the technology magazine *Wired* holds the following view:

> "When we talk about the new economy, we're talking about a world in which people work with their brains instead of their hands. (...) A world in which innovation is more important than mass production. A

[1] The Internet address is http://hotwired.wired.com/special/ene/. Search results date from May 2004.

> world in which investment buys new concepts or the means to create them, rather than new machines. A world in which rapid change is a constant. A world at least as different from what came before it as the industrial age was from its agricultural predecessor. A world so different its emergence can only be described as a revolution."

Contrasting these enthusiastic words, the *Google* result ranked second for the same key words is somewhat sobering. It is www.fuckedcompany.com, a homepage that defines itself as the "official lubricant of the new economy". This web site reveals news about numerous Internet companies whose success has been not all that revolutionary: they have gone out of business or are in serious trouble. Benefiting from this apparent demise of the *New Economy*, the site charges a monthly fee of $ 40 for full access to a database including rumours, comments, and internal memos forwarded by employees of troubled companies. It was even prized "site of the year" by *Yahoo!*, the *Rolling Stone*, and the *TIME* magazine.

These search results illustrate fairly well how close enthusiasm and disillusions still coexist in what was widely believed to become a *New Economy*. Experience during the last years has been quite mixed, with spectacular bankruptcies, frauds, and stagnating ICT markets on the one hand and ever more powerful electronic networks and a highly robust productivity growth in many countries (in particular in the U.S.) on the other. Against the background of these ambiguous facts, the occasionally fierce debate between apologists of a *New Economy* and its critics in the past has given way to a much more differentiated discussion of the topic.

ICTs comprise a large variety of items. These include not only products and services of information technologies (e.g. mainframes, personal computers, software, ICT maintenance services) but also telecommunication equipment and products, such as telephones, fax machines, telecommunication infrastructure and services as well as services by Internet providers. In the remainder, I sometimes refer to 'computers and the Internet' as the most popular applications of ICT. This alternation in denomination, however, is not meant as defining a subgroup of ICT but rather as an alternation in wording that is employed synonymously for the very broad notion of ICT.

There are no disagreements about the impressive technological advances that have been achieved in the worldwide production of ICTs. The computing power of microprocessors has been doubling about every 18 months since the 1950s (a development that is widely known as *Moore's Law*). And the more recent inventions from the past three decades like personal computers, notebooks, CD and DVD players, mobile phones, or the Internet are just a few examples of products and services that would have been unthinkable to be developed without the rapid technological progress in the ICT sector.

There is no doubt either that these developments have been largely beneficial for consumers of ICT goods and services. The technical advances and competition in the ICT sector have been strong enough to make prices for

ICT goods (and partly services as well) fall very rapidly over the last decades. In 1970, one megahertz of processing power cost $ 7,600 and one megabyte of storage amounted to $ 5,200. In 1999, both items were sold for only 17 cents (Woodall, 2000) and have continued to fall since then. This means that a large part of the productivity gains achieved in the ICT sector have been passed to downstream sectors and consumers.

What is more controversial and remains subject to debate in the economic literature is the question to what extent ICTs have initiated innovations and productivity gains also in other parts of the economy that may become a source of sustained overall economic growth. More recent contributions in the economic literature on 'endogenous' economic growth theories have highlighted the role of innovation and human capital formation as important drivers of economic growth in industrialised countries. These theories treat growth as an endogenous economic variable by considering technical advances as the outcome of economic decisions instead of treating them as exogenously given. To the extent that ICTs contribute to making innovation and human capital formation more productive (making 'rapid change a constant', in the above mentioned Encyclopedia's words), these theories predict the diffusion of ICT to raise the long-term growth potentials of industrialised economies.

Several economists have identified in ICT the characteristics of a *general purpose technology* (GPT) as being pervasive (i.e. employed in large parts of the economy), entailing a large potential for technical improvements, and facilitating or 'enabling' technological advances also in wide parts of the overall economy. With respect to these characteristics, the invention of the computer has frequently been compared to other important inventions in the past. The invention of the steam engine, for example, did not only allow to employ more powerful machines in mining and manufacturing. It also facilitated the invention and broad application of the railway which became an important source of increasing trade and productivity gains during the industrial revolution. Moreover, the invention of electricity towards the end of the 19th century not only substantially lowered the costs of artificial light, but also allowed enterprises to extend their operating hours and to reorganise production processes. Similarly, the largest benefits from ICT may accrue not from computers simply substituting typewriters and other types of equipments, but from firms using it as a tool for own innovational activities and adjustments, such as the improvement of products and services, changes in work organisation and processes, or new task compositions of workplaces.

These *general purpose* characteristics of ICT are the main topic of this monograph. Provided that ICT is primarily an *enabling* technology, the essential part of its contributions to productivity will be contingent upon certain firm strategies and complementary efforts. This contingency will be reflected both in firms' behaviour regarding input or strategy choices and in productivity differences between firms. The theoretical and empirical analyses of this monograph thus refer to various aspects of one central question: *to what* *extent and favoured by which complementary strategies has the use of ICT been contributing to firm productivity?* Answering the question what must be done to make ICT investments work productively is of interest for businesses, economists and policy-makers alike. Addressing this question both theoretically and empirically, the subsequent chapters devote special attention not only to the measurement of ICT productivity but also to the role of innovation activities and investment in employee training as prominent examples of complementary strategies to ICT use.

The empirical parts of the monograph are based on two large-scale surveys among German firms conducted by the Centre for European Economic Research (ZEW). The first source, the *ZEW survey on ICT*, contains data from nearly 4,500 firms in manufacturing and services on the use and diffusion of ICT in 2002. The second source, the Mannheim Innovation Panel in Services (*MIP-S*), consists of annual data from about 2,000 firms over the period 1994-1999. Jointly, these two data sets form a capacious basis to explore the productivity effects of ICT use and its consequences on firm behaviour from two complementary points of view: How does ICT use affect firms' choice of strategies? And how does the combination of ICT use and these strategies affect firm productivity?

Based on these data sets, this monograph contributes to the existing empirical literature on the productivity effects of ICT in five main respects: it stresses firm-level differences; focusses on the case of a European country; accounts for the importance of small and medium-sized enterprises; highlights the consequences of ICT use in services; and addresses important methodological issues in productivity measurement.

First, employing two large-scale sets of data from firms in Germany, this work complements existing macroeconomic studies on the topic. These aggregate analyses have documented substantial aggregate productivity gains in industrialised countries that can be attributed to the production and use of ICT. However, they are not suited to map any differences in how firms adopt ICT. These differences may form a key in understanding the impacts of ICT as a GPT but are wiped out in the process of data aggregation. Firm-level data, in contrast, allow to identify strategies associated to ICT use, like particular innovation activities, organisational changes or training efforts. Moreover, they facilitate to scrutinise whether additional complementary strategies (e.g. own innovation efforts) help to raise the productivity of ICT. These complementary aspects are particularly important since they are supposed to characterise ICT as an *enabling* input that distinguishes itself from other types of investments in equipment or structures.

Second, existing empirical efforts on the topic have primarily focussed on the United States, probably for two main reasons. First, the U.S. economy has been at the frontier of productivity and living standards for several decades and is strongly engaged both in the production and adoption of ICT. And second, the availability of relevant data (at firm, industry and aggregate level) is particularly well developed in the U.S., facilitating a variety of analyses that are simply impossible to conduct for other countries. However, economic conditions in Europe — and Germany in particular — are fairly different, with most countries in continental Europe being subject to stronger regulations of product and labour markets. Moreover, during the last decade, the U.S. economy has been much more dynamic in terms of GDP and productivity growth. U.S. results can thus not necessarily be generalised to other countries. The analyses in this monograph avoid U.S.-centricity and resort to data from representative surveys among firms in Germany as the largest European economy.

Third, most firm-level studies on ICT have focussed on large firms or corporations listed at the stock markets. Consequently, little is known about the impacts of ICT on small and medium-sized firms which form a particularly important part of the German economy and account for roughly 70% of employment. Both data sets employed in this monograph contain information on firms with five and more employees. The analyses from this monograph thus provide results that also apply to smaller companies that have been widely neglected by firm-level studies to date. To highlight this issue, the empirical parts of this monograph provide detailed information on the size distribution of the firms in the samples employed.

Fourth, while the productivity effects on manufacturing is fairly well documented, only few studies have explored the impacts of ICT on services. A stronger focus on services, however, seems worthwhile for at least three reasons. First, ICT investment is most pronounced and most dynamic in the service sector. Second, business-related services have been important drivers of economic growth over the last decades in industrialised countries and account for about two thirds of gross domestic product (GDP) in Germany (as in most other industrialised economies). Finally, quality changes are particularly difficult to measure in services and are frequently understated in official price statistics. ICT, in turn, is frequently used for raising productivity by enhancing the quality of products and services. This work (in particular chapter 3) highlights that firm-level studies may be better suited than aggregate analyses to account for productivity effects that result from improved output quality.

Fifth, measurement of productivities is a tricky issue even if large-scale samples are available. The major concern is reverse or spurious causality: instead of ICT being productive, it may be that well-managed firms are both more productive and more disposed to ICT applications. Similarly, firms tend to invest (in both ICT and other assets) during boom periods when demand, factor utilisation and productivity are high. In the empirical analysis I will employ suited panel-data approaches to address these (and other) methodological issues econometrically.

In essence, the analysis in this monograph proceeds as follows. Chapter 2 motivates the view on ICT as a GPT based on a fairly general theoretical framework and some empirical facts. The subsequent chapters then focus on assessing the productivity gains from ICT. Chapter 3 scrutinises various methodological issues in productivity measurement and derives a preferred econometric approach that captures the average impacts of ICT on firm productivity. Extending this approach, chapters 4 and 5 then investigate to what degree the productivity contributions of ICT are contingent on firms' innovative activities and on human capital investment. Heterogeneous efforts with respect to these complementary strategies are found to be important sources of varying capabilities of firms to use ICT productively.

In order to facilitate selective reading of individual parts of the monograph, the individual chapters are conclusive enough to be read likewise as independent studies on various aspects of ICT as a general purpose input to production. In addition, the autonomy of the chapters is reflected by the fact that each of them contains an extensive review of the literature concerned with the correspondingly relevant topics.

The content and main results of the individual chapters are as follows. Chapter 2 discusses *general purpose* characteristics of ICT and explores first theoretical, then empirical issues. The former part discusses economically relevant theoretical aspects of GPTs (pervasiveness, potential for technical improvements, innovational complementarities) and illustrates that ICTs broadly satisfy these properties on the basis of some examples. I then present theoretical approaches that are commonly used in the economic literature for assessing the economic consequences of these properties on productivity growth and on the choice of complementary strategies in firms. For this purpose, I review approaches in the tradition of growth accounting analyses and discuss a model of complementarities based on the fairly general mathematical concept of supermodularity.

In the empirical part, results from the *ZEW survey on ICT* are used to provide several statistical facts on firms in Germany highlighting the GPT properties of ICT. Based on the same data, I then use correlation and econometric regression analysis to identify strategies that are pursued by firms with high ICT use. The results indicate that various indicators of ICT use (including ICT expenditures and PC use in firms) are all strongly correlated with training measures. Moreover, the use of personal computers in firms is broadly adopted for innovating processes and distribution channels, such as e-commerce, supply chain management, outsourcing, and customer relationship management. Organisational changes that are targeted at increasing workers' autonomy are also correlated to ICT use. However, these correlations turn out to be mainly the result of product and process innovations facilitated by ICT use.

Chapter 3, which is drawing substantially on Hempell (2005b), focuses on assessing average productivity effects from ICT use at the firm level. In a theoretical part, I first show that quantitative analyses employing firm-level data are less affected by imperfectly measured changes in output quality and prices than analyses employing aggregate data. I derive a partial equilibrium model that interprets production function results at the firm level as the reduced-form outcome of a market equilibrium, where firms that increase output quality by ICT use are remunerated by gains in sales volume due to higher equilibrium prices. I then illustrate that measuring productivity contributions of ICT is subject to a variety of further biases. Interfering factors such as differing management abilities, qualification of employees, measurement errors, simultaneity of input and output decisions by firms as well as business cycles may lead to distortions in the quantitative results.

These effects are illustrated in the empirical part by applying different econometric techniques to panel data from the *MIP-S* survey covering, the years 1994 to 1999. Once all the mentioned interfering influences are controlled for, ICT is found to have, in fact, enhanced productivity in German services. These productivity contributions are increasing with the share of highly educated workers in firms. The overall productivity contributions as assessed are, however, substantially smaller than those obtained in various existing studies on the topic that do not consider the various methodological issues involved in the present econometric analysis. I find unobserved time-invariant characteristics to be the most important source of bias for estimated productivity of ICT. In order to control for these firm effects and other sources of bias, I employ instrumental approaches that exploit the panel structure of the data. The preferred econometric approach based on the Generalised Method of Moments (GMM) likewise forms the basis for the in-depth analysis of ICT productivity in the two subsequent chapters.

Chapter 4, which draws on Hempell (2005a), considers the role of product and process innovations for successful ICT use and highlights the role of innovative histories of firms. As illustrated in chapter 2, ICT investment is closely linked to complementary innovations. ICT use enables firms to restructure their internal organisation and to re-engineer business processes. The ability to innovate successfully, however, may well be determined by the learning effects compiled in the course of a firm's history. Innovation activities do not only create new knowledge but also help to accumulate expertise that eases exploitation of externally available knowledge. Moreover, they facilitate subsequent own innovation activities either in a specific technological field (e.g. ICT applications) or in terms of changes to organisational routines. I argue that due to the enabling character of ICT applications, the success of ICT use may thus depend on a firm's innovative history: given that ICT use is productive only with complementary innovations, firms that have introduced innovations in the past will be better prepared for using ICT than firms without such innovation experience. Consequently, productivity effects of ICT are predicted to be higher in firms with innovative experience.

In the empirical analysis, this hypothesis is broadly backed by econometric results. These results show that experience from past process innovations play a particularly important role, at least in the service sector to which the analysis is applied. The productivity contributions of ICT in firms that have introduced process innovations in the past are about five times as high as among other firms. Robustness checks show that this finding cannot be attributed to the fact that the skill level of the workers is positively correlated to both ICT use and innovation activities. Ignoring the historical dimension of innovation, however, yields smaller and statistically insignificant results. Jointly, these findings indicate that innovative trajectories are important determinants of the success of ICT applications in firms. The arrival of ICT as an increasingly better and cheaper GPT seems to favour firms that have already pursued innovation strategies in the past.

Chapter 5 investigates the consequences of ICT use for training requirements. Computers and networks increasingly allow workers to share access to databases, to connect their workplaces and to co-ordinate business processes with suppliers and clients. These changes in the composition of work tasks require a continuous updating of workers' skills. As illustrated in the first chapter, ICT applications may require firms to provide their workers increasingly with ICT-specific training. Beyond these technical aspects, ICT use may call for increased training efforts if firms complement ICT use by innovations and reorganisation of workplaces.

In the empirical analysis for German service firms, training expenditures are defined more broadly than in the analysis from chapter 2. The *MIP-S* data include not only ICT-specific training but also other types of training, e.g. in new tasks, processes, or communication and language skills. The econometric analysis shows that firms complement ICT investments by training programmes for their employees. Corroborating similar findings from chapter 2, training and ICT investments are highly correlated even if varying firm characteristics, such as e.g. industry and size, are taken into account. In addition, production function regressions also point to synergies between ICT use and training investments. I employ stocks of accumulated training expenditures to consider potential lags in the effects of training courses and to treat training as an investment instead of current expenses. The results from productivity analyses show that firms with investment in both training and ICT perform significantly better than those competitors engaged in more isolated investment strategies. An important prerequisite for this combined investment to work, however, is a high share of well-educated employees in the workforce. Obviously, the educational level of workers not only contributes directly to firm productivity but also forms a key factor for the effectiveness of training. Moreover, the chapter also assesses to what extent increases in wage costs reduce incentives of firms to invest in training measures. The results show that such disincentives exist, but are mitigated by ICT investments: the share of productivity gains that can be appropriated by the investing firm is higher in firms with sizeable ICT investment. These findings imply that falling prices of ICT entail both the requirement as well as an incentive for firms to provide training programmes for high-skilled workers.

In a final concluding chapter, I summarise the main results of the monograph and put them into a broader perspective. In particular, I assess the relevance of the results by comparing them to some more recent macroeconomic developments. Finally, I argue that innovative capabilities and skills of workers were not only relevant during the 1990s but are likely to stay so at least in the near future.

2

Impacts of ICT as a general purpose technology

I think there is a world market for maybe five computers.

Thomas Watson, chairman of IBM, 1943

Where a calculator on the ENIAC [the world's first digital computer] *is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1,000 vacuum tubes and perhaps weigh 1.5 tons.*

Popular Mechanics, March 1949

If it should ever turn out that the basic logics of a machine designed for the numerical solution of differential equations coincide with the logics of a machine intended to make bills for a department store, I would regard this as the most amazing coincidence that I have ever encountered.

Howard Aiken, pioneer of the computer industry, 1956

2.1 Introduction

Looking back some decades, the success story of the computer resembles a true miracle. As the quotes above illustrate, the potentials of computers have been widely underestimated even by ICT professionals with respect to at least three important dimensions. First, the world market for computers obviously exceeds the number five forecasted by Thomas Watson in 1943, reaching several hundred millions of mainframes, PCs and notebooks worldwide today. Second, the potential for technical improvements turned out to be large enough to ensure that employees today do not have to sit in front of 1.5 tons of vacuum tubes when using their computers. And third, the scope of use for computers has become so large that computers do not only solve differential equations and make bills for department stores but in fact today comprise a scope of highly elaborated purposes.

During the last decades, computers, the Internet and other applications of ICT have turned from helpful computational machines into indispensable tools in industrialised economies. Anticipating a number from section 2.4.1, about every second employee in Germany uses a computer at work and ICT (including software) accounted for nearly 42% of real investment expenditures of the German business sector in 2002, up from about only 8% in 1970 (Deutsche Bundesbank, 2004). The dominant role of computers in today's social and economic activities has been the result of rapid technical advances in computing potentials and manifold complementary inventions in related technological fields (such as laser technology or telecommunication) whose various mutually stimulating impacts could hardly be foreseen.

At the heart of ICT's success story is the ever increasing computing power of microprocessors and increases in memory components' storing capabilities. The boost of computing and storage power has continuously broadened the scope of use of ICT. A distinctive criterion for measuring the continuing progress is computing power per size of ICT equipment. Since the end of the 1950s, the number of transistors per square inch in a microprocessor has doubled about every eighteen months, a development that is widely known as *Moore's Law*.[1] In the course of this development, the introduction of the 1043 byte memory chip in 1969 and the silicon microprocessor by Intel one year later have been highlighted as important breakthrough events (David, 1990). At the same time, the technological advances in ICT production have gone along with a competitive pressure in the ICT-producing sector,[2] making prices of hardware drop at rates between 15 and 30% annually (OECD, 2003).

A particularly important innovation in the continued technical progress in the ICT sector was the invention of the personal computer (PC) and its mobile version, the notebook, that allowed to apply digital information processing and storage power to particular and personalised purposes (David and Wright, 1999). Simultaneously, the software industry developed more and more applications that allowed users to employ the computer in many more functions than just as a machine to solve mathematical problems. Increased computing power coupled with standardised software have led the computer to successively replace type writers, balance sheet books, audio tapes, cameras

[1] Barnett et al. (2003) provide a detailed discussion of Moore's Law, its forecasting power and its role as a self-fulfilling forecast. Jovanovic and Rousseau (2002) present a theoretical model of Moore's Law where efficiency of computer production rises as a by-product of experience.

[2] Aizcorbe (2002) reports evidence that Intel's markups from its microprocessor segment shrank substantially during the period from 1993-99, an observation that points to increased competition from other producers of microprocessors.

as well as television, making it resemble more and more a general purpose tool rather than a mere calculating machine.

Technical advances have thereby not been limited to the ICT sector. The increasing computing, storing and communication potentials of ICT have also facilitated a variety of innovations in products and services in other sectors of the economy. For example, cars are increasingly equipped with microcomputers that operate navigation systems and monitor operations of car components. Similarly, computers also facilitated new kinds of services. Cash machine tellers, online banking, e-commerce, and web-based after sales services are only some examples of how ICT has changed the character of services. Most importantly perhaps, ICT is used to improve the quality of existing products and services, in particular customer service, timeliness and convenience (Brynjolfsson and Hitt, 1995; Licht and Moch, 1999).

Finally, and maybe most importantly, ICT applications have great impacts also on processes and organisation inside firms and administrations (Bresnahan and Greenstein, 1996). Firms employ more flexible and more easily programmable manufacturing tools that incorporate ICT (Milgrom and Roberts, 1990); supply chain management tools increasingly link the production processes of suppliers and clients; and new tools for customer care, such as customer relationship management, help to recognise changes in demand more quickly (Hammer, 1990; Rigby et al., 2002). In various cases, these developments are associated with substantial organisational changes prompting prolonged implementation periods and often new skill requirements for workers (Brynjolfsson and Hitt, 2000).

These forces of ICT supply and demand are mutually reinforcing. Advances in ICT facilitate new economic activities which in turn demand more powerful computers to support their innovations (Milgrom et al., 1991). For example, ICT and the Internet have facilitated e-commerce, while the demand for digitalised products such as software, music and films was an important driver to foster the further development and diffusion of broadband access.

These developments have motivated researchers to designate ICT as a *general purpose technology* (GPT) and to compare it to other important inventions in the past such as electricity and the steam engine (David, 1990; Helpman, 1998; Rosenberg and Trajtenberg, 2001). A common feature of these inventions is that they have contributed significantly to overall productivity, economic growth and welfare.

However, GPTs have not favoured all firms and individuals equally. The invention of the steam engine, for example, has made firms more and more independent from the proximity of water power as a source of power supply for manufacturing. This has favoured cities as production sites due to agglomeration advantages while penalising rural locations (Rosenberg and Trajtenberg, 2001). These differences are important since the adjustment costs associated with a firm's change in production location are substantial. Analogously, firms are probably not equally well endowed to take advantage of ICT. The more difficult and more costly it is to adapt to the requirements of new